

The Future of RHIC

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Exploring the Phases of Nuclear Matter

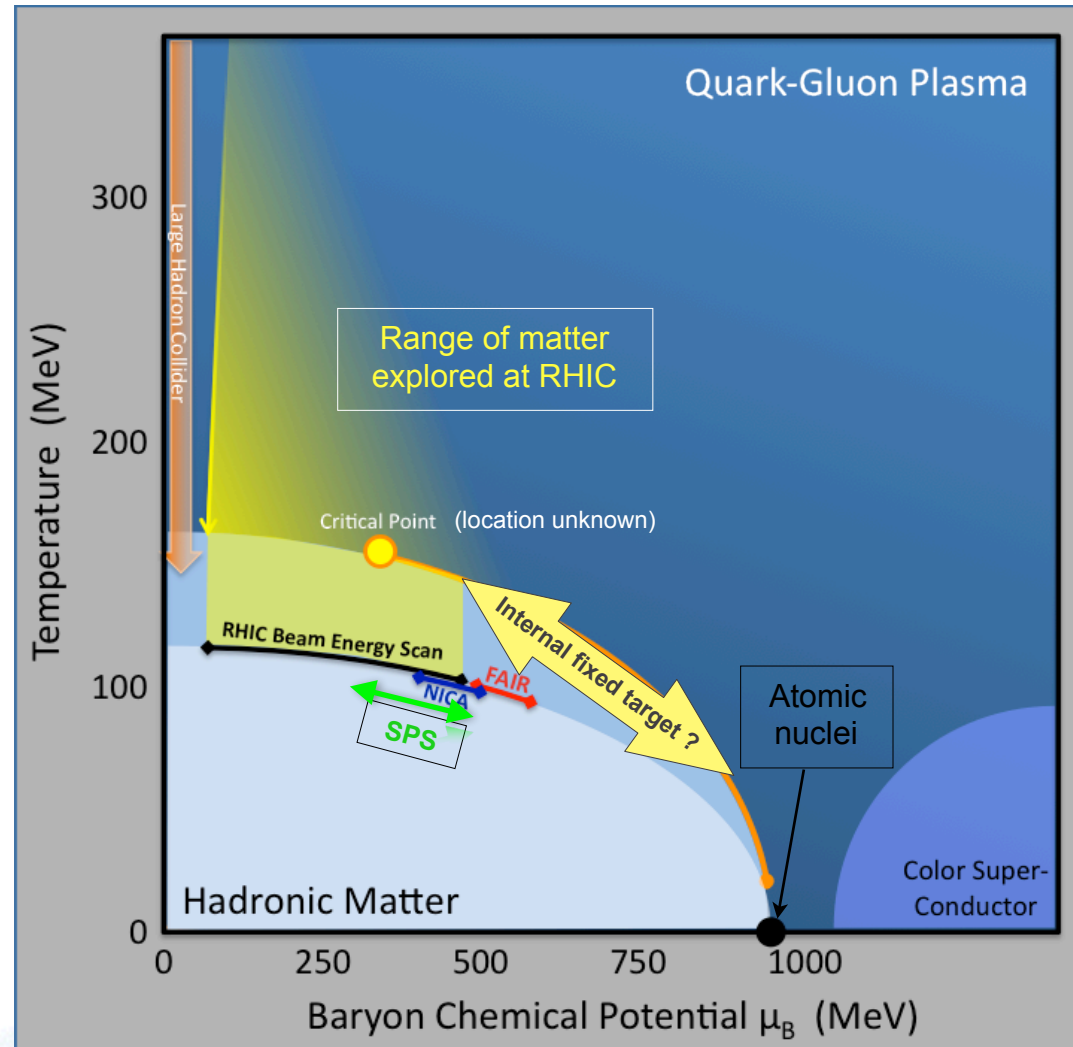
RHIC: Spans largest swath of the phase diagram in the preferred collider mode. Many collisions systems possible.

LHC: High energy collider at CERN with 13.8 - 27.5 times higher beam energy. Pb+Pb, p+Pb, p+p collisions only.

SPS: Fixed target program covering the HG-QGP transition region.

FAIR & NICA: Planned European facilities at lower energies.

RHIC has defined an eight-run-year program to complete its scientific mission. We just completed Year 2.



Open Questions

- What can pp, pA, and AA collisions tell us about the **internal structure** of the colliding protons and nuclei?
- Is QGP **equilibration** the result of dynamical chaos in a **weakly coupled *glasma***, or is it the result of inherently **strong** coupling?
- What is the smallest collision system that behaves **collectively**?
- What does the **QCD phase diagram** look like? Does it contain a **critical point** in the HG-QGP transition region? Does the HG-QGP transition become a **first-order phase transition** for large μ_B ?
- What is the **structure of the strongly coupled QGP** at varying length scales? What makes it a liquid?
- Can we **quantitatively deduce the properties** that characterize the QGP by comparing simulations with the data?

2015 Long Range Plan

RECOMMENDATION I

The progress achieved under the guidance of the 2007 Long Range Plan has reinforced U.S. world leadership in nuclear science. The highest priority in this 2015 Plan is to capitalize on the investments made.

- *Complete and run CEBAF 12 GeV upgrade*
- *Complete FRIB at MSU*
- *Targeted program in neutrinos and fundamental symmetries*
- ***The upgraded RHIC facility provides unique capabilities that must be utilized to explore the properties and phases of quark and gluon matter in the high temperatures of the early universe and to explore the spin structure of the proton.***

Priorities for RHIC

- Complete the characterization of the transport properties of the quark-gluon plasma with heavy quarks
- Use the polarized proton beams of RHIC to explore the dynamics of helicity and spin in QCD
- High-statistics survey of the QCD phase diagram in a second beam energy scan using cooled beams
- Precision study of the microscopic structure of the liquid quark-gluon plasma with complete jet and heavy quark measurements
- Timely transition to an electron-ion collider

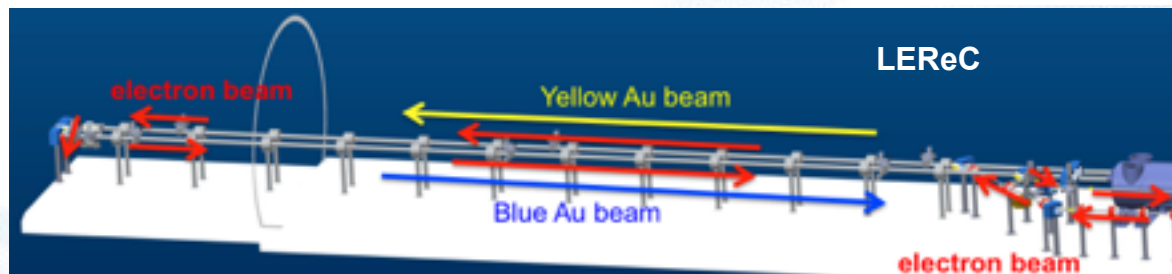
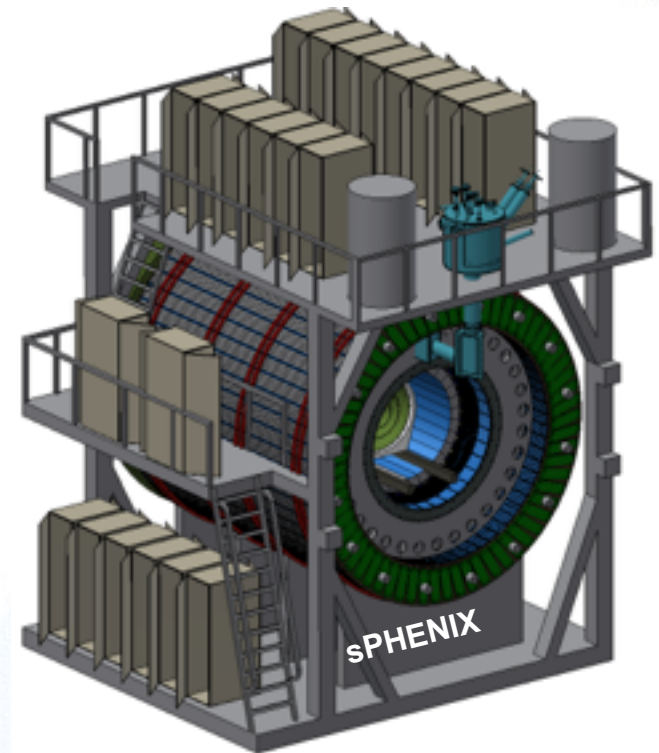
Completing the RHIC science mission

Status: RHIC-II configuration is complete

- Vertex detectors in STAR (HFT) and PHENIX
- Luminosity reaches 25x design luminosity

Plan: Complete the RHIC mission in 3 campaigns:

- 2014–17: Heavy flavor probes of the QGP using the micro-vertex detectors; Transverse spin physics
- 2018: Install low energy e-cooling (LEReC)
- 2019/20: High precision scan of the QCD phase diagram & search for critical point
- 2021: Install sPHENIX
- 2022–23: Probe QGP with precision measurements of jet quenching and Upsilon suppression
- Transition to eRHIC ?



FAQs

- Why did the schedule for sPHENIX slip by one year?
 - Our original plan had no runs in 2017 (to install LEReC) and 2020 (to install sPHENIX). Stretch-out of LEReC required moving first year w/o RHIC run to 2018; we dropped the 2020 no-run year to keep sPHENIX schedule on track. Shift 2017 to 2018 delays investment profile, making sPHENIX completion in 2020 unrealistically aggressive.



- Will sPHENIX take data for more than 2 years?
 - Maybe. This depends on many things: Is there a truly compelling forward physics program? When can EIC construction start? Etc.
 - There will be a new Long Range Plan process in ca. 2022, where this question will be discussed.
 - The Collaboration should work to develop the physics case for extended running.

What RHIC will deliver

■ Campaign 1 (2014-17):

- QCD equation of state at $\mu_B \approx 0$
- Precision measurement of $\eta/s(T \approx T_c)$
- Measurement of heavy quark diffusion constant $D_{c/b}$
- Measurement of x-dependence of nuclear granularity
- Origin of single spin asymmetries
- Δg , flavor dependence of spin in the quark sea

■ Campaign 2 (2019-20):

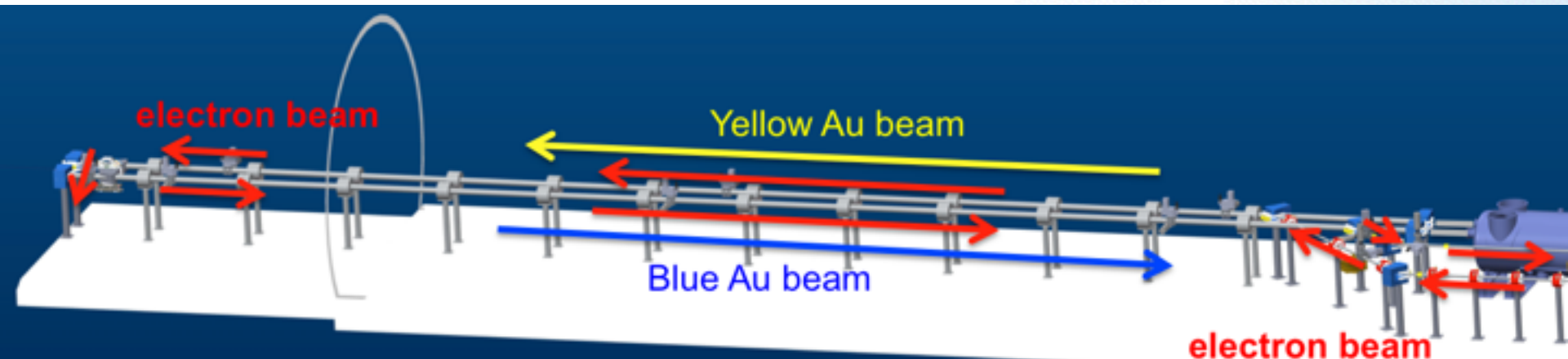
- QCD equation of state at $\mu_B > 0$
- Discovery of the QCD critical point, if within the accessible range

■ Campaign 3 (~2022-23):

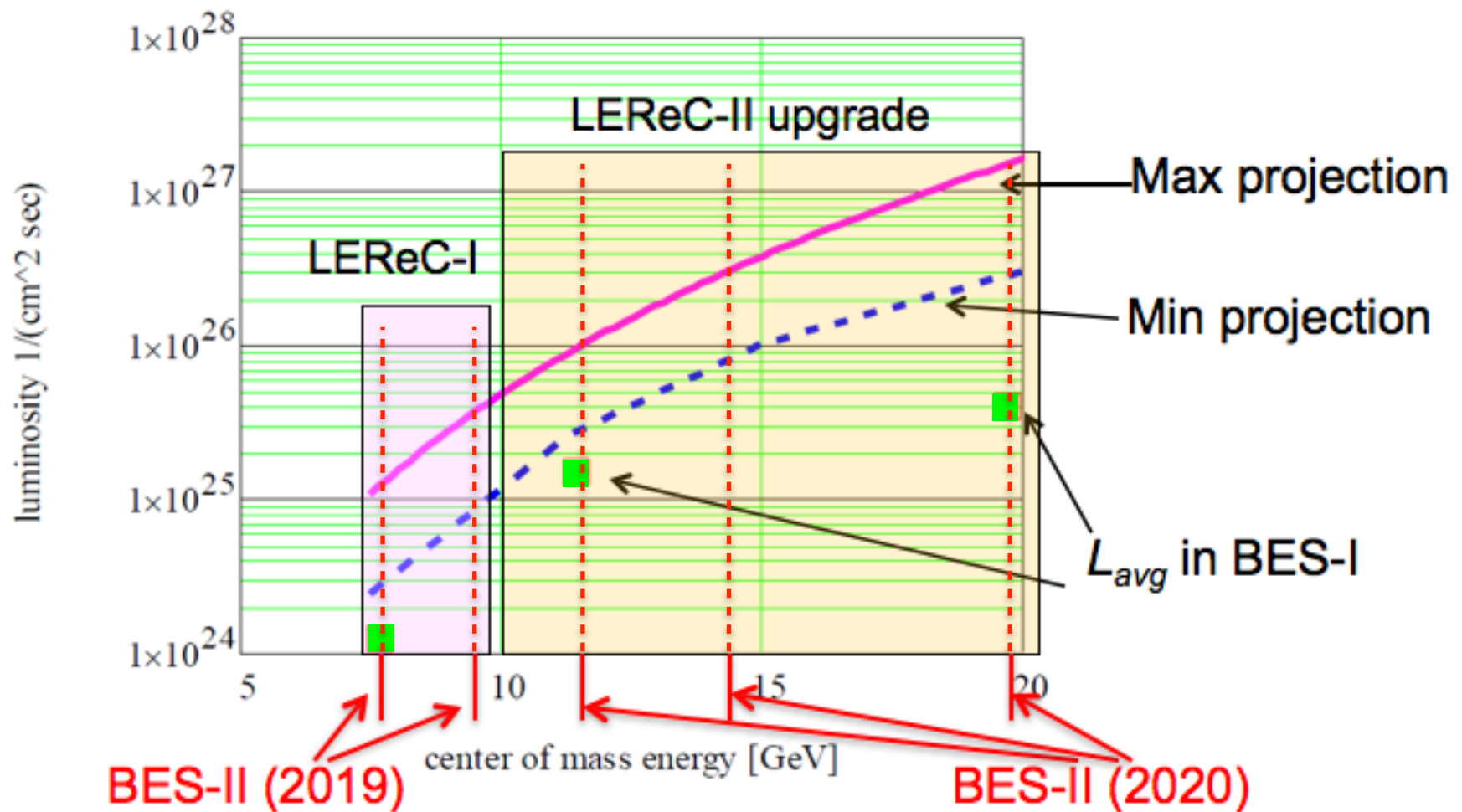
- Precision measurement of $q^{\wedge}(T \approx T_c)$ and $e^{\wedge}(T \approx T_c)$
- Determine length scale where the QGP becomes a liquid
- Many additional insights we can't anticipate

Low Energy e-Cooling for Au+Au

- Cooling of low energy heavy ion beams (3.8–10 GeV/n) with bunched electron beam increases luminosity by up factor 10
- Enables a QCD critical point search with a high statistics Beam Energy Scan
- Use either SRF electron gun or Cornell DC electron gun (for risk mitigation) and existing SRF cavity for cost effective implementation
- Stage 1: $\sqrt{s_{NN}} \leq 10$ GeV; stage 2: $\sqrt{s_{NN}} \leq 20$ GeV
- Cost: \$8.3M (stage 1)
- Complete installation in 2018, use in low energy RHIC runs in 2019-20



BES-II luminosity



**How do asymptotically free quarks and gluons
create the near-perfect liquidity of the QGP?**

or

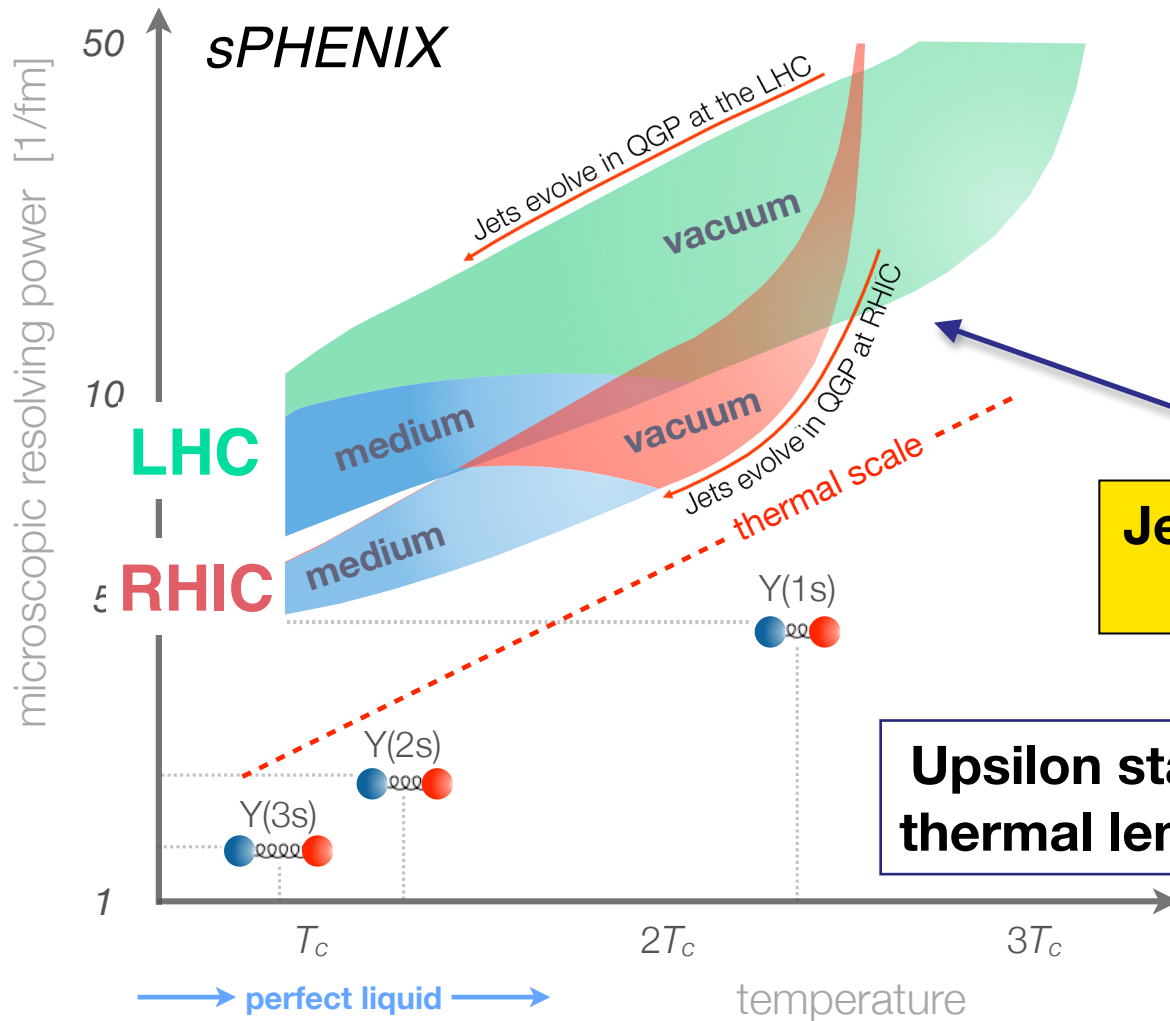
**What degrees of freedom
not manifest in the QCD Lagrangian
produce the near-perfect liquidity of the QGP?**

The (experimental) answer:

**Deploy probes with a resolution that reaches from the
thermal scale of the bulk to the sub-thermal scale:**

Jets & Upsilon states

Probing scales in the medium



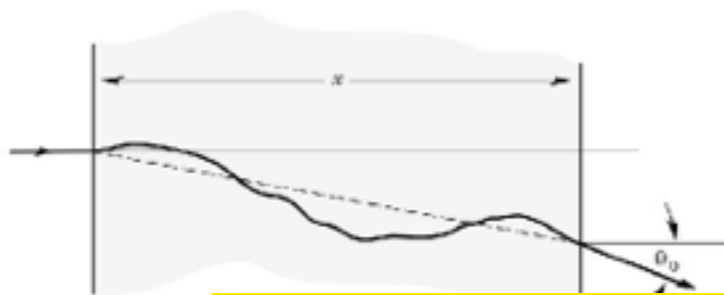
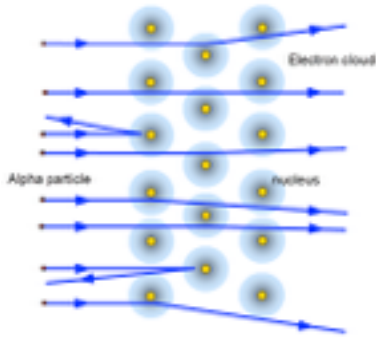
How does the perfect fluidity of the QGP emerge from the asymptotically free theory of QCD?

Jets probe sub-thermal length scales

Upsilon states probe thermal length scales

“Rutherford” meets QGP

At what scale do discrete scattering centers
“dissolve”
into a collectively acting, continuous medium?

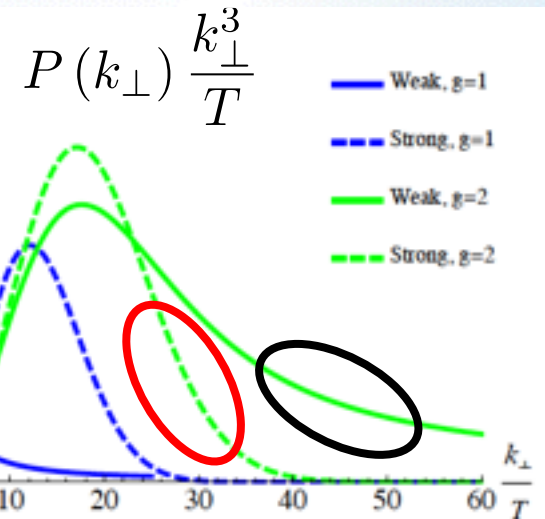
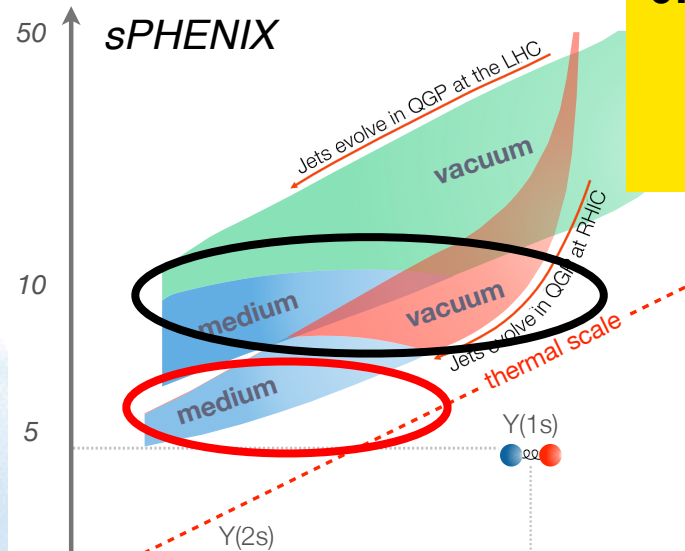


Point-like scattering centers:
 $1/k_T^4$ tail

Quasi-continuous medium:
Gaussian

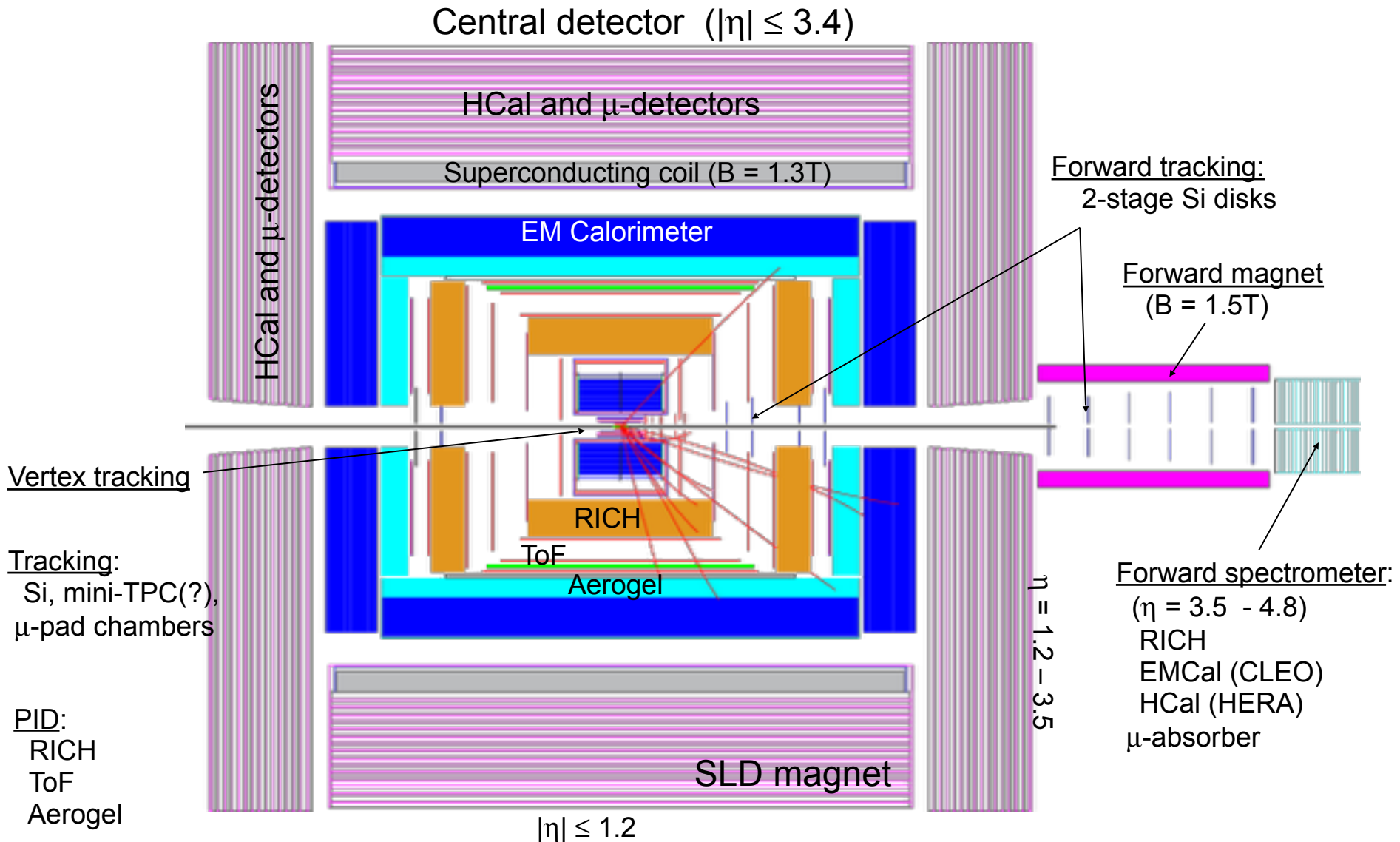
**sPHENIX will sample
0.6 trillion collisions!**

**10x more than is
possible at LHC**

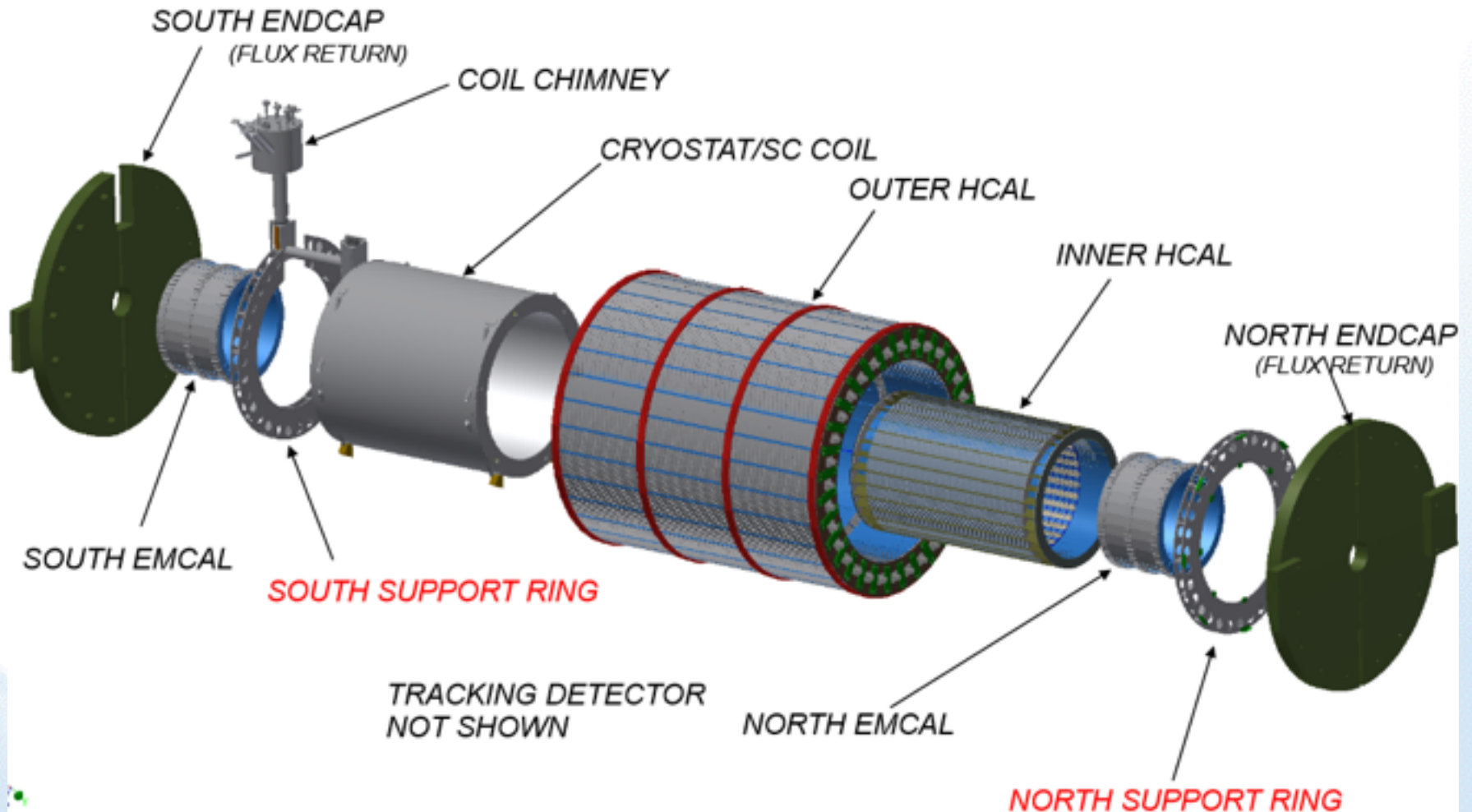


**The scientific goal of elucidating
the microscopic structure
of the liquid quark-gluon plasma
with hard probes at RHIC requires
a high DAQ rate capable detector
with excellent calorimetry and
precision tracking capability**

Comprehensive New Detector at RHIC



sPHENIX exploded view



Other Opportunities?

- New RHIC Spin Plan is currently under development
 - Draft mid-December, final version due end of January 2016
- STAR outline of physics opportunities beyond 2020
 - PAC: Case not compelling enough now for investments in upgrades
- fsPHENIX: Collaboration issue
 - Are there compelling physics opportunities? What are they?
 - Requirements on magnet configuration?
- ePHENIX: Work with EIC users community
 - Upgrade capability is an important decision criterion
 - Requirements on magnet configuration?
 - Beam intersection region considerations?
 - Compatibility of technology choices?

Challenges for sPHENIX

- Keep maturing the science case
 - JET Collaboration is over
 - There is no Quarkonium Collaboration
 - Keep the theorists engaged and preparing for the data
- Optimizing the detector design
 - Tracking
 - Calorimetry
 - Magnet flux return
 - Requires many simulations and openness to alternatives
- Broadening the community
 - Reach out to the STAR community
 - Keep developing the case for cold QCD measurements
 - Establish liaison to EIC community
- Perseverance
 - Tough choices and hard times are just around the corner!

Collaboration - Project - Lab

- sPHENIX can only succeed, if all three entities work together constructively
- Each entity needs to understand its role in the process
- Collaboration represents the scientific program, serves as think tank, essential component of the work force, advocates - everything the Lab and the Project cannot do
- Project is accountable to the Lab and DOE; Collaboration is only accountable to itself and the scientific community
- Tension is natural; communication is critical
- sPHENIX formation is without precedent at collider facilities
- Your enthusiasm and commitment is crucial